PLATE TECTONIC CONSTRAINTS ON THE BIOGEOGRAPHY OF MIDDLE AMERICA AND THE CARIBBEAN REGION

PETER J. CONEY[1]

ABSTRACT

North America-Eurasia and South America-Africa were certainly joined in the classic reconstruction of Pangaea by Middle Triassic time. The line of collision and suture included the Appalachian Quachita-Marathon orogenic trend in the United States extending southwestward into what is now northeastern and southeastern Mexico and into Guatemala. Widespread continentality prevailed and there was no Gulf of Mexico or Caribbean Sea. In Late Triassic time and continuing into Early Jurassic time this construct began to founder by initial rifting between South America-Africa and North America. No oceanic crust was formed, however, thus Africa-South America were still completely connected by land or shallow sea to North America until mid-Jurassic time. During this same uppermost Triassic to Middle Jurassic period a largely continental magmatic arc was draped across the Pacific margin of southwestern North America and apparently continued unbroken into northwestern South America.

Sometime in the Middle Jurassic oceanic crust began to form by seafloor spreading in the central Atlantic and Gulf of Mexico as separation of South America-Africa from North America accelerated. Once this dense crust began to form the trailing margins of the continents subsided below sea-level and construction of the Atlantic and Gulf coast continental shelves began. Evidence is quite conclusive that this ocean floor spreading did not reach the Pacific Ocean, but was transformed from the southwestern corner of the newly opened Gulf of Mexico northwestward across Mexico via a complex left-slip transform fault system that reached the Pacific margin near Los Angeles.

In Early Cretaceous time spreading continued in the central Atlantic but extended southward into the southern Atlantic. As the main axis of spreading extended into the south Atlantic, spreading ceased in the Gulf of Mexico. The south Atlantic spreading initiated separation of South America from Africa, but they probably remained in partial contact via ridge-ridge transform faults until Late Cretaceous time. South America must have finally completely separated from North America in Early Cretaceous time, probably via a rift along the eastern edge of Yucatan and the Nicaraguan rise.

By Late Jurassic time the Pacific continental margin arc had waned and was replaced by a complex, largely oceanic, magmatic arc whose position relative to southwestern North America and northwestern South America is not known. What we do know is that by Late Cretaceous-Early Tertiary time it had accreted against the Pacific margins of both. Connections between the continents are also not known but could have included a largely submarine magmatic arc, parts of which may have subsequently dispersed eastward as the Greater Antilles. Much of what is now Middle America is apparently underlain by oceanic crust at least as young as Late Cretaceous in age.

By Late Cretaceous time the Greater Antilles magmatic arc seems to have fully formed and subsequently moved northeastward as a northeast-facing subduction system during Late Cretaceous-Early Tertiary Laramide time.

The Greater Antilles arc-trench system ceased activity in Late Eocene time as it collided with Florida and the Bahama platform and as Laramide orogeny waned throughout western North America. This was followed by a major plate reorganization in the Caribbean-Middle America region nearly 40 m.y. B.P. which established the Caribbean plate more or less as we know it today. The principal change was initiation of the Lesser Antilles magmatic arc as an east-facing subduction system that began to consume Atlantic ocean floor. Also, a west-facing subduction system may have formed about this time along a proto-Central American western margin of the Caribbean plate. However, much of what is now Central America may have initially been off southern Mexico. The northern and southern margins of the Caribbean plate evolved into complex transform and transpressive systems as North and South America moved westward past a nearly stationary Caribbean plate. These motions significantly fragmented the Greater Antilles into their present array. There is no evidence for any complete land connection between North and South America via the Greater and/or Lesser Antilles throughout later Mesozoic or Tertiary time. Nor is there any evidence for complete land connection via Central America and the Isthmus of Panama before Neogene time.

[1] Department of Geosciences, University of Arizona, Tucson, Arizona 85721.

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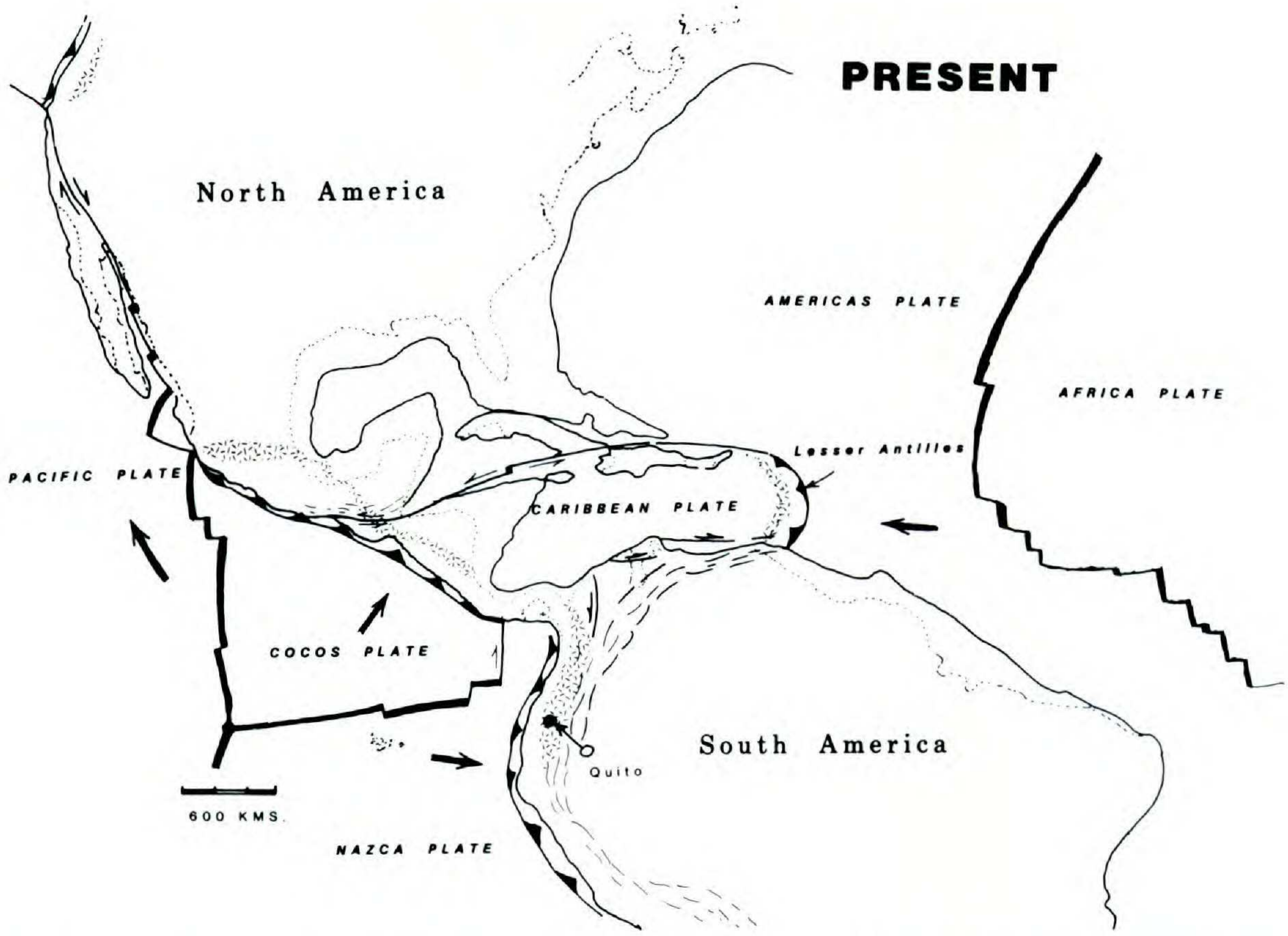

FIGURE 1. Present plate configuration. The six major plates and their motions are shown. Heavy black lines are spreading centers or rise crests; heavy, barbed lines are subduction zones; dashes pattern shows distribution of magmatic arcs. Dotted line is present coastline of the continents, solid line seaward is edge of continental crust. Opposed arrows on transform faults connecting rise crest segments show sense of relative motion on fault.

INTRODUCTION

Plate tectonics (see Cox, 1973) has provided for the first time a quantitative means to make reasonably accurate global paleogeographic reconstructions for Mesozoic-Cenozoic time. This new-found ability has enabled great insight into regional tectonic evolution of both the oceans and continents, and the implications for paleoclimatology, paleo-oceanography, and paleobiogeography are only just beginning to be fully explored. The objective of this paper is to outline plate tectonic arguments regarding the paleogeographic evolution of Middle America and the Caribbean region and adjacent North and South America (see also Dickinson & Coney, 1980). This hopefully can provide a paleotectonic background against which biogeographic arguments can be compared. It should be realized by the biogeographic community, however, that the resolution level of paleotectonic reconstruction is frequently coarser than that desired by biogeographers. In that sense it is possible that paleobiogeographic data may be as helpful to paleotectonics as is the reverse, which makes symposia such as this very propitious.

THE PROBLEM OF THE MIDDLE AMERICA-CARIBBEAN REGION

The present plate tectonic setting of the Middle America-Caribbean region is generalized in Fig. 1. The relationships are not simple and in their complexity lies in part the problem of this region. Six plates are found here all interacting in a complex way.

The Pacific plate, which floors most of the Pacific Ocean, is moving[2] northwestward as it spreads away from the East Pacific rise. It is carrying Baja California and the State of California west of the San Andreas fault with it as it moves. The Cocos plate is moving northeastward away from the East Pacific rise and Galapagos rise and is being subducted beneath southern Mexico and Middle America along the Middle America trench. The Nazca plate moves eastward away from the East Pacific rise and Galapagos rise and is subducting beneath South America. North and South America, probably as separate plates, move generally westerly away from the Mid-Atlantic rise. Caught in the middle of all these motions is the Caribbean plate. Its motion is not well known, but it is probably moving very slowly if it is not essentially stationary. The Caribbean plate subducts Atlantic sea-floor beneath the Lesser Antilles on the east, and Cocos and Nazca plate beneath the Middle America region on the west. Its northern boundary is a complex transform fault system and its southern boundary is an even more complex transform-transpressive fault system. Both of these fault systems accommodate the motions of North and South America as they move generally westward past the Caribbean plate. They are probably slightly converging one upon the other and upon the Caribbean plate as they move.

The problem in the Caribbean region is that the two "Atlantic" plates of the Americas and the three "Pacific" plates all spread from rise crests and thus leave magnetic anomalies painted on the sea-floor as they spread. This allows, by backing-up dated anomalies sequentially to the rise crest, rather accurate reconstructions of relative plate positions. In contrast, no such data exists for the Caribbean plate, since, with the exception of a small rise crest in the Cayman trough, it is surrounded by subduction zones or transform faults. As a result, no complete record of motion with respect to other plates is preserved. Therefore the history of the Caribbean plate must be deduced from controlled motions of adjoining plates combined with the geologic and geophysical (see Martin & Case, 1975; and other papers in Nairu & Stehli, 1975) record preserved on the Caribbean plate itself. This kind of information is at best always somewhat equivocal and subject to varied interpretation. The model proposed here is perhaps one of several permissible interpretations (for example, see Malfait & Dinkelman, 1972). Certainly, in a region as poorly known and complex as this one, new information and insight

[2] Plate motions can only be described as motions with respect to some frame of reference. There are two general methods. In purely relative motion schemes the motion of a plate is described with respect to an adjacent plate, which for computational purposes is assumed to be fixed (see Ladd, 1976). A second approach is the so-called "absolute" motion scheme. Here plate motions are described with respect to some reference frame outside the plates themselves. Usually the chosen frame is the assumed rotational axis of the earth which is derived from paleomagnetic data and from the positions of assumed semi-fixed thermal anomalies or "hot spots" in the mantle. These "hot spots" produce intra-plate volcanism such as the Hawaiian Islands. As a plate moves over a "hot spot" a trail of volcanic edifices such as the Hawaii-Emperor seamount chain can be produced. If the edifices can be dated an "absolute" motion of the plate is derived. Then, using relative motions between this plate and other plates, the motions of all the plates with respect to the fixed reference frame can be attained. The motions discussed in this report are this second, or "absolute," type (see Coney, 1978).

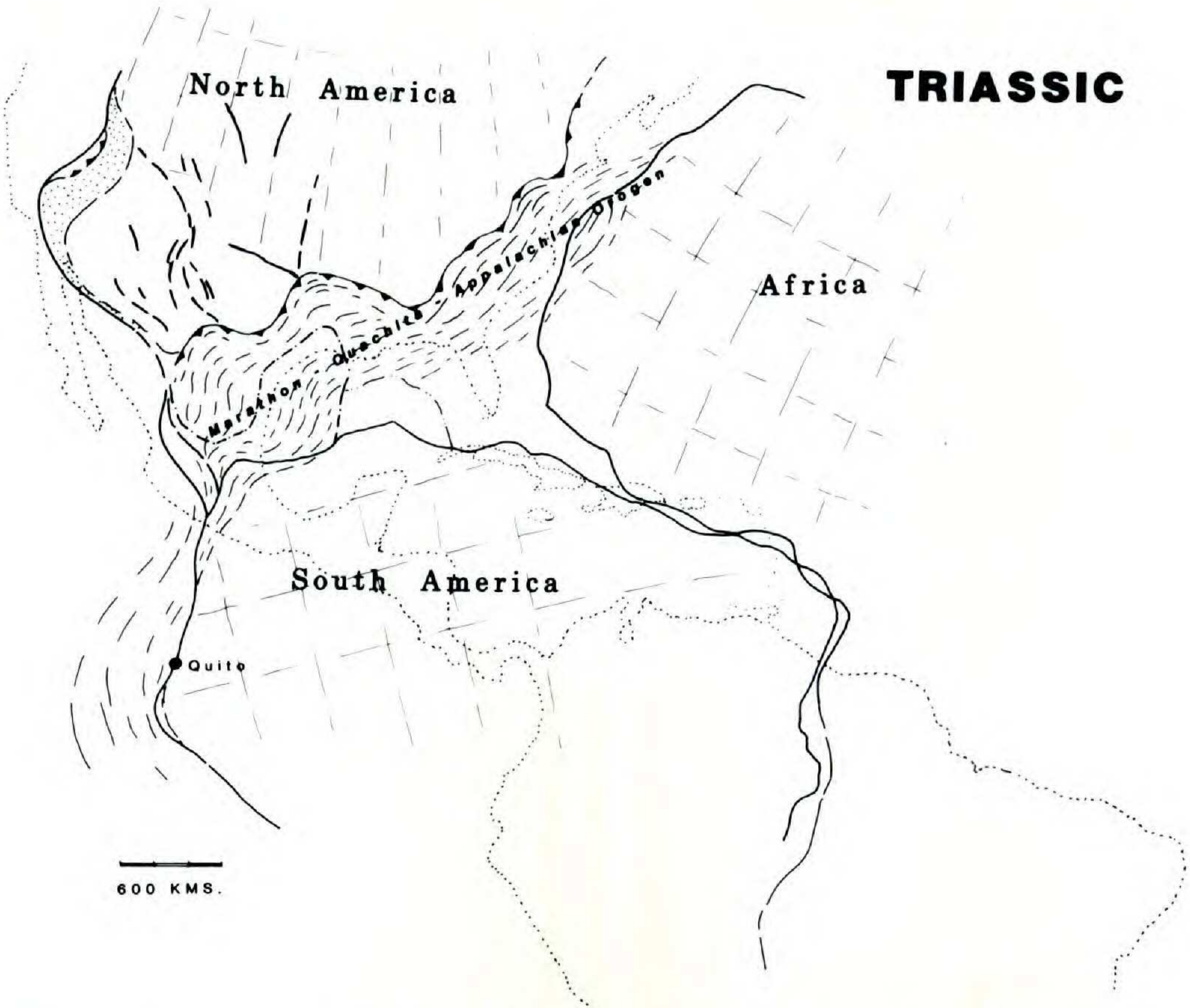

FIGURE 2. Triassic plate configuration. Dashed light lines forming grid are generalized present-day lines of latitude and longitude. Deformation associated with the Appalachian-Marathon-Quachita orogeny shown by wavy lines. Dot pattern is Cordilleran miogeocline.

could force significant revision of today's conceptions, including what is presented here.

TRIASSIC

The reconstruction for Triassic time is shown in Fig. 2. It is the classic configuration of Pangaea (see Irving, 1977) as manifested in the Caribbean-Middle America region. This reconstruction derives from closure of the central Atlantic Ocean controlled by the magnetic anomalies there, which places Africa close against the margin of eastern North America. Since South America was still stitched to Africa at this time, what one does with Africa one must also do with South America. This predetermines the position of South America with respect to North America. South America is shown overlapping all of what today is the Caribbean Sea, Middle America, and almost one-half of Mexico. This is a geometric fact from which one must conclude that all the rocks and lands included within the overlapped region either did not exist at this time or they were somewhere else (Coney, 1978).

The assumption is that the line of suture between Africa-South America and North America resulted from Late Paleozoic collision and possible right-lateral strike-slip faulting between the two continental masses to produce the Appalachian-Quachita mountain system (Graham et al., 1975). The final consolidation, certainly completed by Late Triassic time, is the reconstruction shown in Fig.

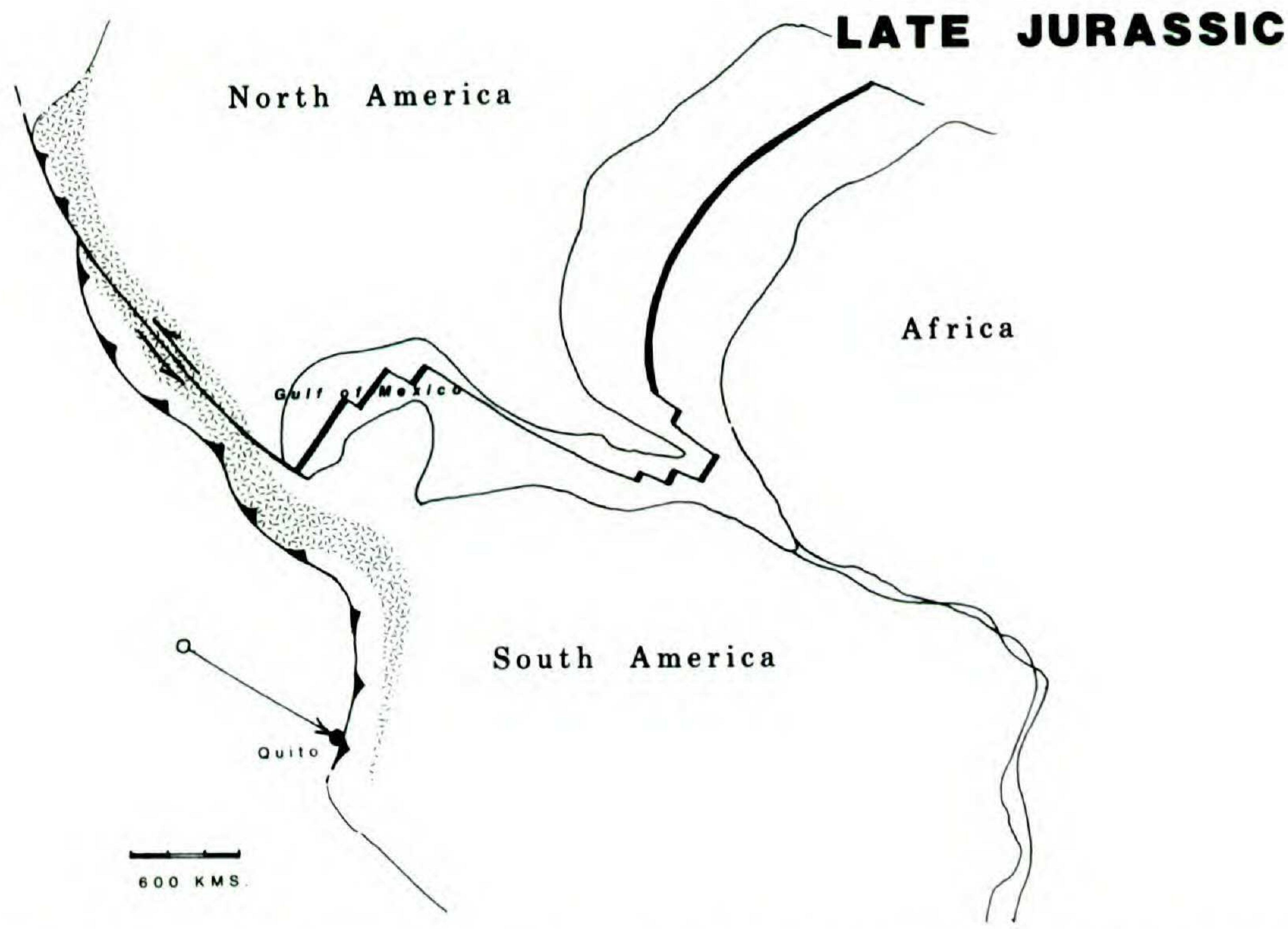

FIGURE 3. Late Jurassic plate configuration. On this and subsequent figures the position of Quito, Equador is shown with respect to North America assumed fixed. The arrow indicates the amount of movement this position made during the period following the previous figure. The Mojave-Sonora "megashear" is shown by heavy line with opposed arrows indicating sense of movement.

2. Widespread continentality prevailed throughout the region and there was no Gulf of Mexico or Caribbean Sea, nor any Atlantic Ocean. In short, Africa-South America-North America were a single landmass and the region was everywhere above sea-level.

LATE JURASSIC

The reconstruction for Late Jurassic (Fig. 3) shows the central Atlantic Ocean and Gulf of Mexico opened as Africa-South America separated from North America. Paleomagnetic data suggests that North America moved rapidly northwestward relative to a near-stationary Africa-South America. The process of rifting and separation probably began in Late Triassic time by inception of extension between the two major blocks. There is considerable geologic and geophysical evidence for widespread development of rift valleys and ridges as continental crust began to extend. Continentality prevailed as the rifted basins filled with debris shed off adjacent highlands and uplifted blocks. By Middle Jurassic time extension had reached sufficient amounts such that inter-connected down-faulted and subsided areas allowed distal incursions of shallow marine water, probably from the Tethys Ocean north of Africa and south of Europe. Evaporation of these incursions produced widespread salt and other evaporite deposits that are well known throughout the Gulf of Mexico region today.

Once oceanic crust began to form in Middle Jurassic time the margins of the newly rifted continental masses began to subside rapidly due to higher density of new oceanic material and thermal decay of the continental margins. This allowed widespread marine transgression upon the newly formed continental margins from the Atlantic and Gulf of Mexico oceanic basins. The transgressions initiated development of the continental shelves as sediments were draped across the bared edges of the continents. This decelerating process of shelf development has continued to the present time.

There is some evidence to suggest that the young rift between Africa-South America and North America did not reach the Pacific Ocean. It appears to have been transformed northwesterly across Mexico as a major left-slip fault system. This complex fault may have extended from the southwestern corner of the newly opening Gulf of Mexico northwestward to the Pacific coast near Los Angeles in southern California. This important feature has been termed the Mojave-Sonora "megashear" and estimates are that up to 800 kilometers of left-slip movement took place along it between Late Triassic and Late Jurassic time (Silver & Anderson, 1974).

During this same period, between Late Triassic and Late Jurassic time, a volcanic-magmatic arc developed along the Pacific margin of North and South America. The feature seems to have been almost everywhere above sea level standing on continental crust and extending unbroken between the two continents. The implication is that in spite of over 800 kilometers of relative separation between Africa-South America and North America, and in spite of the formation of the central Atlantic Ocean and Gulf of Mexico as deep marine basins between them, the two supercontinents remained in above or near sea-level contact via Mexico until Late Jurassic-Early Cretaceous time. That Africa and South America were still joined, thus both in contact with North America via Mexico, has significant implications for Jurassic reptilian interchange between East Africa and western United States (Galton, 1977).

Early Cretaceous

The reconstruction for Early Cretaceous time is the least reliable and subject to considerable uncertainty. Based on the spreading history in the central Atlantic, we know that Africa continued to separate from North America, but spreading in the Gulf of Mexico apparently ended by Late Jurassic time. We also know that spreading between Africa and South America began in Early Cretaceous time. These geometric facts demand continued separation of South America from North America but without spreading and transform movements in the Gulf of Mexico and along the Mojave-Sonora megashear. This necessitates spreading between the two continents in what might be termed a proto-Caribbean sea (Fig. 4). It must be recalled, however, that no record of this spreading has been positively identified to date. It is simply a construct apparently demanded by plate geometry.

By Late Jurassic time the Pacific margin-continental margin magmatic arc had waned and was replaced by a complex, largely submarine oceanic magmatic arc whose position was apparently somewhere off-shore of the Jurassic continental margin (Campa & Coney, in press). The hypothetical spreading center between North and South America may have extended southwestward to join with various Pacific spreading centers. If correct, a deep ocean basin may have separated North America and South America during part of Early Cretaceous time.

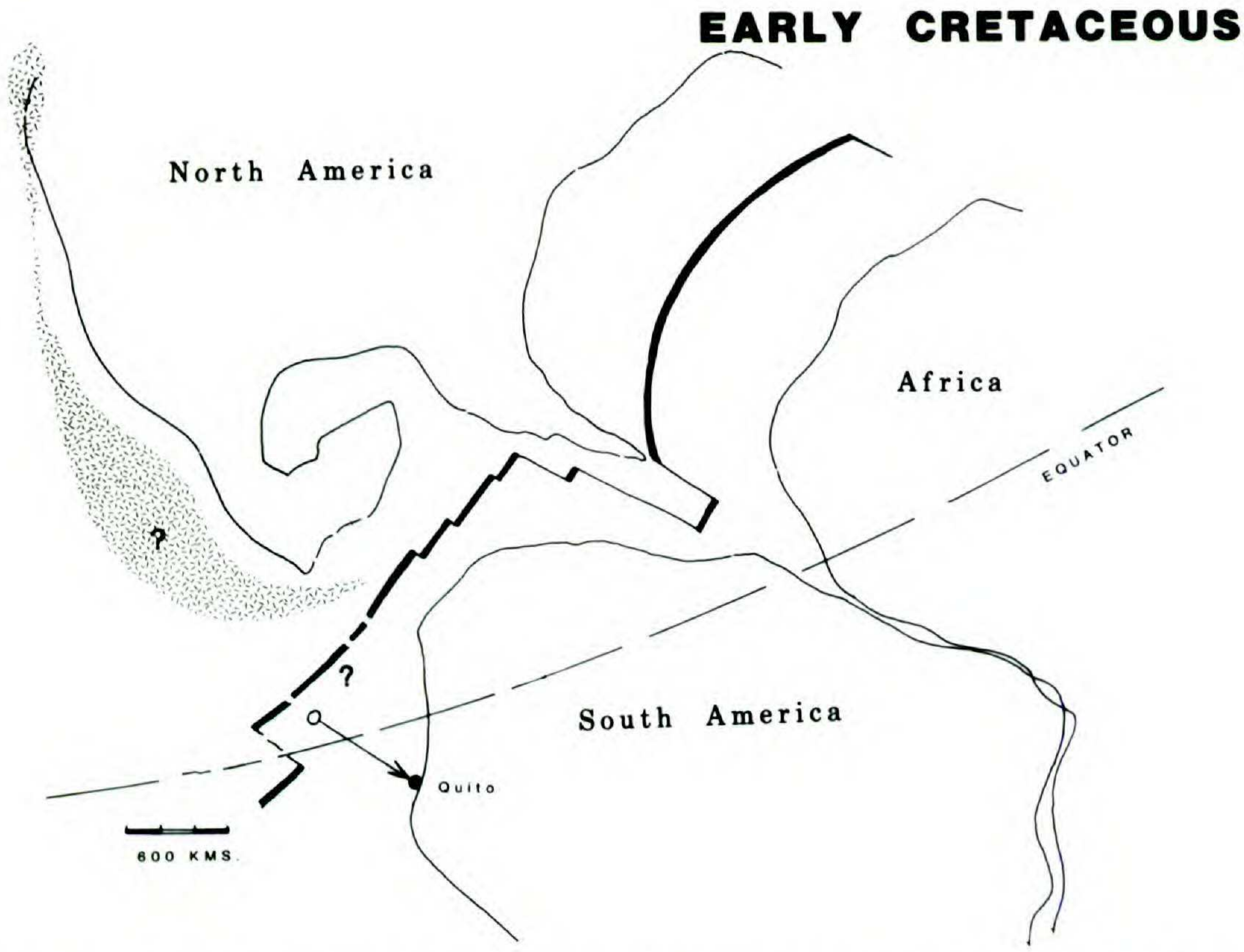

FIGURE 4. Early Cretaceous plate configuration. Symbols as on previous figures. The assumed spreading center between North and South America is shown projecting into the Pacific Ocean.

LATE CRETACEOUS

The reconstruction for Late Cretaceous (Fig. 5) is nearly as equivocal as that for Early Cretaceous and it is certainly plagued by uncertainties that may be years from resolution. Spreading had started in the south Atlantic separating Africa from South America, but these continents were perhaps in close contact across transform faults between northeastern Brazil and the west African coast. The principal enigma, however, is the geology between North and South America.

We do know that on several islands of the Greater Antilles rocks at least as old as Middle Cretaceous have the aspect of a submarine volcanic arc (see Khudoley & Meyerhoff, 1971). This suggests the proto-Greater Antilles formed as a submarine volcanic chain that presumably stood above a subduction zone. The most likely location of this subduction zone was off-shore of the Pacific-American margin far to the southwest of the present position of the Greater Antilles. It may have been part of the off-shore Cretaceous arc discussed earlier that stood southwest of Mexico. This arc apparently had accreted against North America by Late Cretaceous-Early Tertiary time and may have simply extended southeastward across the growing gap between North and South America. It was subsequently swept northeastward through the widening gap that was to become the Caribbean Sea.

The Cretaceous arc is of interest, if it existed as portrayed, since it could have harbored faunas and floras upon its far-flung volcanic islands, which were swept eastward as the arc migrated toward its present position. It could have also provided "stepping stones" for dispersals between the two continents during

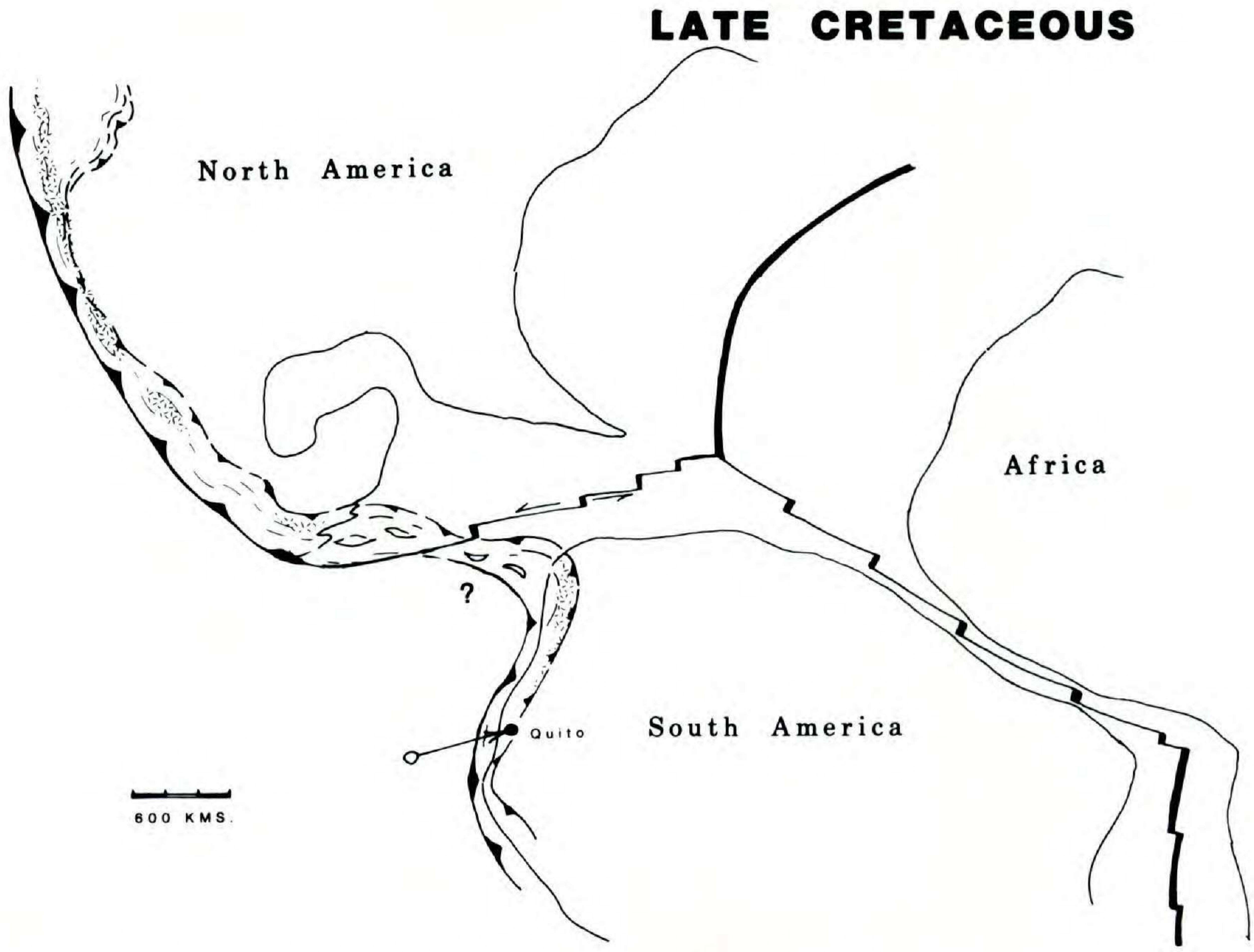

FIGURE 5. Late Cretaceous plate configuration. Symbols as on previous figures. The Cretaceous volcanic arc is shown accreting against North and South America and connecting the two continents by scattered volcanic islands.

Middle and Late Cretaceous time. The linkage was, however, no more than scattered islands and fringing reefs, probably much like present-day Lesser Antilles.

EOCENE

The Eocene reconstruction (Fig. 6) represents events that culminated from Late Cretaceous to Early Tertiary Laramide orogeny as manifested in the Middle America-Caribbean region. This important orogeny affected the entire North American Cordillera and was important in the Andes of South America as well. It seems to have resulted in part from accelerated convergence rates between one or more oceanic plates in the Pacific realm and the North and South America plates. It may have also been influenced by large scale accretions to the Cordilleran margin of "suspect" (Coney et al., 1980) submarine arcs and lesser lithospheric scraps during this time.

The principal result of Laramide orogeny in the Middle America-Caribbean region was the development of the Greater Antilles as a northeast facing subduction system composed of a largely submarine magmatic arc with a trench on its northeast side (Dickinson & Coney, 1980). The interpretation presented here is that the arc-trench system migrated northeastward relative to North America subducting proto-Caribbean sea-floor beneath it as it moved. This motion eventually caused the system to collide with the Florida-Bahama platform in Eocene

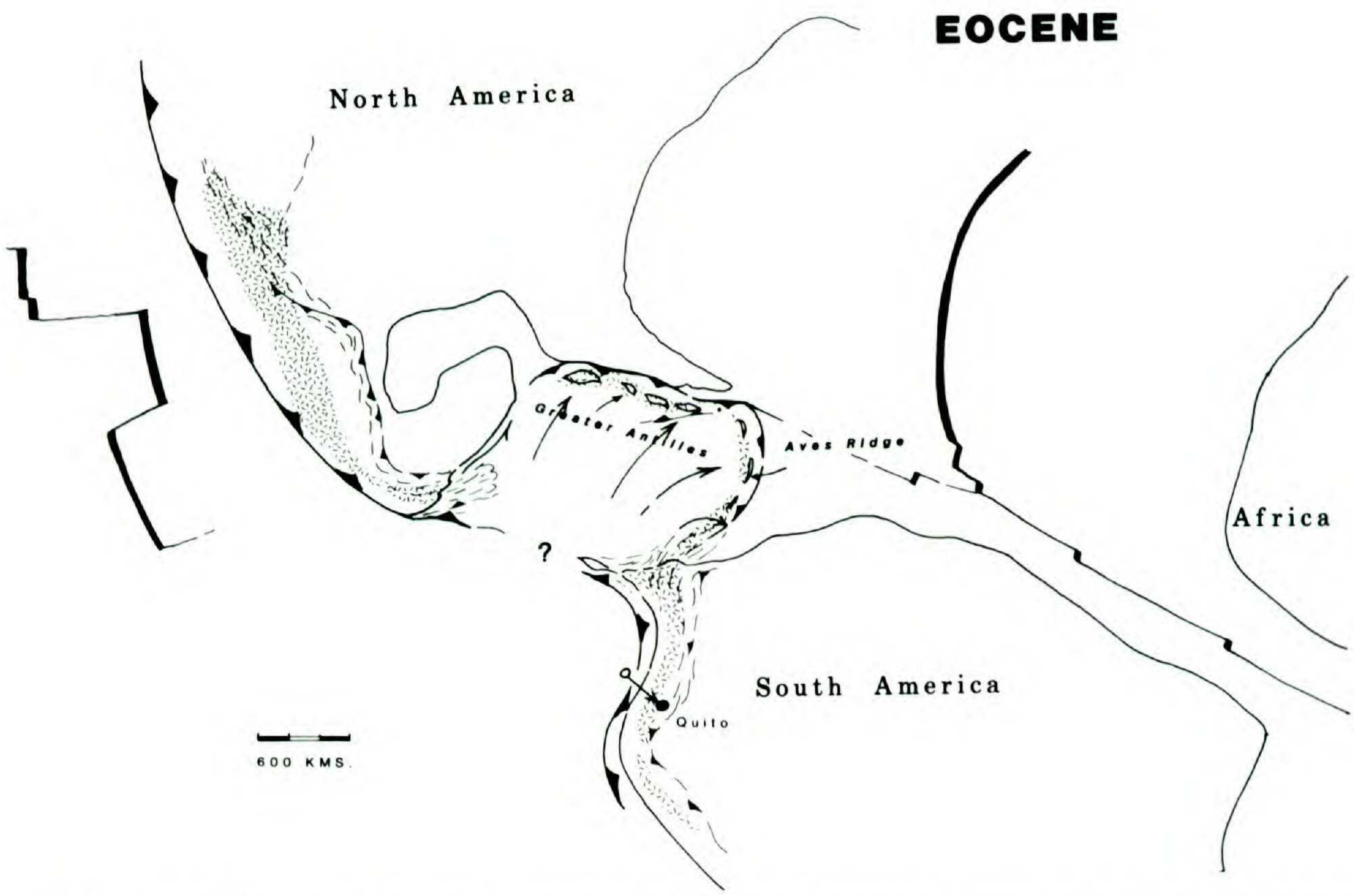

FIGURE 6. Eocene plate configuration. Symbols as on previous figures. The Greater Antilles is shown sweeping into the gap between North and South America and colliding with Florida and the Bahama platform. Soon after the time of this figure plate geometry changed to produce the features shown on Fig. 1.

time. It is assumed that the western end of the system slid northward along a transform fault past the eastern edge of the Yucatan Peninsula. The eastern end of the system is somewhat conjectural, but may have included the now submarine Aves ridge and perhaps part of the Venezuelan Coast Ranges. Paleomagnetic data from several parts of the Greater Antilles-Venezuelan Coast Ranges system suggest significant translations and rotations (see MacDonald & Opdyke, 1972).

If the model presented above is correct, it is assumed that parts of the Greater Antilles may have evolved from the arc system shown on Figs. 3 and 4 for Early and Late Cretaceous time. This arc would then have subsequently swept northeastward and fragmented into the widening gap between North and South America. At all times the system was apparently largely composed of submarine volcanic edifices that occasionally rose above sea-level to form scattered volcanic islands and fringing reefs. These constructions may have partially coalesced by Eocene time. The contact with South America via the eastern end of the system was probably less complete than the contact at the western end with North America. This was because the arc-trench system was forced to extend itself southeastward with time as the two continents continued to separate, and since the arc was actually moving obliquely away from South America.

Middle and Late Tertiary

The Greater Antilles arc-trench system ceased activity in Late Eocene time as it collided with Florida and the Bahama platform. This waning of arc activity was coincident in time with the waning of Laramide orogeny throughout western North America. What followed was a major plate reorganization in the Middle America-Caribbean region, which established the Caribbean plate more or less as we know it today (Fig. 1).

The Caribbean plate was formed by initiation of the Lesser Antilles magmatic arc as an east-facing subduction system that began to consume Atlantic Ocean sea-floor. There is no evidence of the existence of the Lesser Antilles prior to Late Eocene-Early Oligocene time. The arc-trench system seems to have formed just east of the by then extinct Aves ridge. The western edge of the Caribbean plate apparently was a southwest facing arc-trench system along what today is the west side of Middle America. The northern and southern margins of the Caribbean plate evolved into complex transform and transpressive systems as North and South America moved westward and northwestward respectively past a nearly stationary Caribbean plate.

If this model is correct, the Caribbean plate must have been almost 700 kilometers west of its present position with respect to North America and South America. This means proto-Middle America lay south of southern Mexico and the Lesser Antilles southeast of the Bahama platform. The motions of North and South America swept the Caribbean plate relatively eastward and fragmented the Greater Antilles into their present array with Cuba transferred to the North America plate as the Cayman transform evolved. The southern margin of the Caribbean plate was more transpressive since South America's motion was more obliquely northwestward. This has sheared and compressed the Venezuelan Coast Ranges and thrust them southeastward onto South America. The northwesterly motion of South America also served to shorten the distance between North and South America, causing South America to compress and overthrust the Caribbean plate at its western end. This may have flexed the Middle America region into the present twist now seen in Panama and along with collision served to aid in raising it above sea-level in Late Tertiary time to produce the all important land-bridge between the continents (see Case, 1974).

In contrast to the Laramide Greater Antilles, the Cenozoic Lesser Antilles seem to have been much more closely tied at their southern end to South America as they migrated eastward along the Venezuelan coast. Also, the growth and development of a sub-aerial Middle America south of the transform fault zone in Guatemala seems to have progressed southward and eastward toward South America with the final link being collision between Panama and South America in Pliocene time.

Some Summary and Broad Biogeographic Implications

1. During Triassic and Early Jurassic time, widespread continentality prevailed across the entire region and North America-South America-Africa were one landmass part of the super-continent of Pangaea.

2. By Middle Jurassic time, the central Atlantic and Gulf of Mexico opened and by Late Jurassic time both were floored by deep marine oceanic crust. A land connection between Africa-South America and North America persisted via Mexico, however, until Late Jurassic time.

3. During a brief period in Early Cretaceous time, North and South America may have been separated by a spreading center and a growing deep marine basin. Spreading started between Africa and South America in Early Cretaceous time, but land contact may have persisted locally via transform fault margins off present-day northeastern Brazil until Late Cretaceous time.

4. Perhaps as early as Aptian-Albian time a submarine volcanic arc may have provided a connection via scattered volcanic islands between southern Mexico and Colombia-Venezuela. Parts of this arc may have subsequently swept northeastward as the Greater Antilles.

5. The Greater Antilles were perhaps most closely tied to North America via Yucatan and eventually through collision with Florida.

6. The Lesser Antilles were (as they are today) more closely tied to South America during their development from Late Eocene to the present time.

7. Middle America grew sub-aerially southward from North America as a complex volcanic arc-trench system, eventually forming the final land bridge by collision south of Panama in Pliocene time.

8. If overland dispersals between North and South America occurred, they would have been most favored during Triassic and Early Jurassic continentality, then again in Late Tertiary time via the land bridge in Panama. They could have persisted into Late Jurassic time via Mexico. From Late Jurassic to Late Tertiary time only inter-island passages were available.

9. Permo-Triassic non-marine life-forms could have been stranded by isolation on North America and South America from fragmentation of Pangaea. Any land-locked life-forms in the Greater Antilles should be less than Late Jurassic-earliest Cretaceous in age and survival would depend on ability to cope with widely separated and shifting island habitats. Jamaica and Middle America seem more closely tied to Mexico than the Greater Antilles. Finally, there has been considerable fragmentation of the ancestral Greater Antilles through post-Eocene strike-slip faulting between the North American and Caribbean plates.

EPILOGUE

The biogeographic community should be aware that recent developments in the geological sciences strongly suggest that even within the mobilistic concept of plate tectonics there has apparently been considerably more mobility in the evolution of continental margin mountain systems, such as the American Cordilleras, than was recognized only several years ago. The record in western North America, for example (Coney et al., 1980; Coney, 1981), shows that all of Alaska, two-thirds of the Cordillera in western Canada, about 50% of the Cordillera in western United States, and as much as 80% of Mexico (Campa & Coney, in press) are made up of what are termed "suspect terranes." These terranes are suspect because paleogeographic continuity with the cratonic old part of North America cannot be proven through large periods of post-Precambrian time. Paleomagnetic data, stratigraphic and structural data, and distributions of faunas support the concept that many of the terranes are fragments of various sorts swept against North America, some from far-flung reaches of the Pacific Ocean. Most of the accretions onto North America occurred since Middle Jurassic time. The biogeographic implications of all this have hardly begun to be explored.

Literature Cited

CAMPA, M. F. & P. J. CONEY. Tectono-stratigraphic terranes and mineral resource distributions in Mexico. Can. Jour. Earth Sci. (in press).

CASE, J. E. 1974. Oceanic crust forms basement of eastern Panama. Geol. Soc. America. Bull. 85: 645–652.

CONEY, P. J. 1978. Mesozoic-Cenozoic Cordillera plate tectonics. Geol. Soc. America Mem. 152.

———. 1981. Accretionary tectonics in western North America. Ariz. Geol. Soc. Digest 14: 23–37.

———, D. L. JONES & J. W. H. MONGER. 1980. Cordilleran suspect terranes. Nature 288: 329–333.

COX, ALLAN. 1973. Plate Tectonics and Geomagnetic Reversals. W. H. Freeman and Co., San Francisco. 702 pp.

DICKINSON, W. R. & P. J. CONEY. 1980. Plate tectonic constraints on the origin of the Gulf of Mexico. Pp. 27–36 *in* R. H. Pilger (editor), The Origin of the Gulf of Mexico and the Early Opening of the Central North Atlantic Ocean. Louisiana State University Symposium.

GALTON, P. M. 1977. The ornithopod dinosaur bryosaurus and a Laurasic-Gondwanaland connection in the upper Jurassic. Nature 268: 230–232.

GRAHAM, S. A., W. R. DICKINSON & R. V. INGERSOLL. 1975. Himalayan-Bengal model for flysch dispersal in the Appalachian-Quachita system. Geol. Soc. America Bull. 86: 273–286.

IRVING, E. 1977. Drift of the major continental blocks since the Devonian. Nature 270: 304–309.

KHUDOLEY, K. M. & A. A. MEYERHOFF. 1971. Paleogeography and geologic history of the Greater Antilles. Geol. Soc. America Mem. 129: 1–199.

LADD, J. W. 1976. Relative motion of South America with respect to North America and Caribbean tectonics. Geol. Soc. America Bull. 87: 969–976.

MACDONALD, W. D. & N. D. OPDYKE. 1972. Tectonic rotations suggested by paleomagnetic results from northern Columbia, South America. Jour. Geophysical Research 77: 5720–5730.

MALFAIT, B. T. & M. G. DINKELMAN. 1972. Circum-Caribbean tectonic and igneous activity and the evolution of the Caribbean plate. Geol. Soc. America Bull. 83: 251–272.

MARTIN, R. G. & J. E. CASE. 1975. Geophysical studies in the Gulf of Mexico. Pp. 65–106 *in* A. E. M. Nairu & F. G. Stehli (editors), The Ocean Basins and Their Margins, Volume 3: The Gulf of Mexico and the Caribbean. Plenum Press, New York.

NAIRU, A. E. M. & F. G. STEHLI (editors). 1975. The Ocean Basins and Their Margins, Volume 3: The Gulf of Mexico and the Caribbean. Plenum Press, New York. 706 pp.

SILVER, L. T. & T. H. ANDERSON. 1974. Possible left-lateral Early to Middle Mesozoic disruption of the southwestern North American craton margin. Geol. Soc. America, Abs. with Programs 6: 955–956.